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GENOTYPE AND ENVIRONMENT INTERACTIONS OF YIELD CONTRIBUTING CHARACTERS OF FIELD MUSTARD (*BRASSICA RAPA* L.)

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Abstract

Genotype-environment interaction is the norm of reciprocal action that determines the relationship between gene and environmental factors. Gene and environment interaction takes place when different environments affect the genotypes and *vice versa.* The investigation portrays the interaction between genes and environments of yield contributing characteristics of eleven genotypes of field mustard. Three seeding-time environments, viz., early, late, and very late of eleven mustard genotypes were laid out with three replications in a randomized complete block design. Among the three environments, which one was favorable and which was not was determined by their significant differences through a combined analysis of variance. The IPCA 1 (first interaction principal component axis) score of genotypes in the AMMI (additive main effects and multiplicative interaction analysis) of G×E interactions was estimated as an indication of the ability to respond to the environments and the performance with changing environments of the genotypes. Considering all the scores, Sonali Sharisha (SS-75), and BINA Sharisha-10 were found to be highly stable genotypes, while among the three environments, the environment-1 (early sowing) was found the best sowing time for raising and harvesting a good mustard crop.

Introduction

Brassica rapa, commonly known as field mustard or yellow sarson, is widely cultivated as an oilseed crop. *B. rapa* covers almost 70% of the land area of the oilseed crop area of Bangladesh (Rahman et al. 2022). The main reason behind its popularity among farmers' level is due to its dwarf stature as well as its short duration life cycle (75-80 days) compared to *B. napus* and *B. juncea* (Rahman *et al.* 2022). The crop fits well into the Boro rice-based cropping pattern in Bangladesh. In the years of 2020-2021, mustard was cultivated in 814288.54 acres, and total production was 396594.28 M. Ton (BBS 2021). However, the domestic oilseed production of Bangladesh only meets 12% of its requirements. Hence, it is a matter of high concern to increase the oilseed crop production in the country.

The higher crop production depends on the high-yielding potential of the variety, yield contributing traits, and crop management issues. Among management issues, the proper sowing time is regarded as a vital factor to consider, as the sowing time is directly related to the adaptation of the crop varieties. Hence, finding out the proper sowing time is important because yield largely varies with the environment. Umeh *et al.* (2011) reported that delayed sowing leads to a decrease in the plant height and yield performance of mustard crop. Seed yield of mustard declined linearly with late sowing time, mainly due to the shortening of vegetative growth stages, and the yield also varied significantly due to inter-annual variation in climatic parameters (Wang *et al.* 2012) of the growing season. The findings clearly indicate that optimum sowing time ensures the proper growth to guarantee the expected yield of mustard crops. The literature suggests that yield of the

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mustard crop is dependent on how the mustard genotypes interact with differential sowing-time environments.

Expression of plant genotype is dependent on how much the related genes reciprocate with the environment. The regulatory parameters controlling reciprocity are the genetic makeup of a genotype. The notion that genotypes behave differently relative to contexts is disregarded by the means across the environments (Voltas *et al.* 2002). In crop improvement program, promising genotypes are tested for their performance in multiple environments and multiple locations. It is observed that a difference in environment may produce a disparity in the outcome of a genotype. This interplay of genetic and non-genetic effects causes differential relative performances of genotypes in different environments. Genotype-environment (GE) interactions are an important prerequisite in the scheme of selection of improved lines, as these ultimately regulate the genotypes by regulating the correlation between genotypes and the effects of the number of environments on that individual genotype. GE interaction describes how well a genotype performs in different environments.

Repeated testing of a set of genotypes across a wide range of environments is an effective way to investigate the GE interaction. AMMI biplot enables the visualization of the GE interaction and the identification of genotypes that are adopted in particular environments. GE interactions identify genotypes that are broadly adapted, classify environments into groups and measure the stability of a genotype. G×E interaction is characterized by Interaction Principal Component (IPCA), where genotype and environment can be simultaneously plotted in biplots. The G×E interaction is summarized by the two interactions of principal component axes. The IPCA 1 explains the interaction pattern better than other interaction axis. Balestre *et al.* (2009) found that the GGE biplot method was superior to the AMMI 1 graph, due to more retention of GE and G+GE in the graph analysis. Eberhart and Russell (1966) emphasized the need to consider both linear (bi) and non-linear (S^2di) components of genotype-environment interaction in judging the phenotypic stability of a genotype.

The current experiment was uniquely objectified under the target to find out the stable mustard genotypes through comparing the performance of the genotypes in terms of different sowing times, as well as selecting the suitable sowing time for individual mustard genotypes. Keeping this as objective, the yield stability of selected popular mustard genotypes of Bangladesh in three varied sowing-time environmental conditions was investigated.

Methods and materials

Eleven mustard genotypes, e.g., BARI Sarisha-6 (V1), BARI Sarisha-9 (V2), BARI Sarisha-12(V3), BARI Sarisha-14 (V4), BARI Sarisha-15 (V5), Sonali Sharisha (SS-75) (V6), BARI Sarisha-17(V7), Maghi, local popular variety) (V8), BINA Sarisha-10 (V9), BINA Sarisha-9(V10), Improved Tori (V11) were used as plant materials. The experiment was laid out in randomized complete block design (RCBD) with three replications, while the whole plot was sub-divided into 9 blocks with 1m × 3m of unit plot size. Three different environments were used for calculating the G×E interaction in three different sowing times, i.e., early, late and very late. Proper intercultural operations viz. fertilization, irrigation, weeding, thinning, plant protection measures were practiced to raise the good crop as per hand book of BARI (2019).

Data were recorded from ten randomly selected plants from each of the replications under eleven parameters such as plant height excluding root (cm), number of primary branches, number of secondary branches, number of siliques per plant, length of silique (cm), number of seed per silique, thousand seed weight (g), first flowering date, 50% flowering date, date of maturity, and yield per plant (g).

Statistical analysis was performed by the standard procedure followed by Kulsum *et al.* 2013. G×E interaction was estimated and assessed by the AMMI model and IPCA1, respectively (Zobel *et al,* 1988). Eberhart and Russell's (1966) model was used for the estimation of stability parameter, regression coefficient (bi), deviation from regression (S2di), and significance text between S2di and zero by the estimated F-test.

According to Oliveira *et al.* (2010), the AMMI analysis combines in a single model additive components for the main effects of genotype (gi) and environments (ej), and multiplicative components for the effect of G×E interaction (geij). Everhart and Russell (1966) used the following models to study the stability of genotypes under different environments.

Yij= μ + bilj +δij+ eij(i=1,2,...g andj = l,2 ... e)

Where, Yij is the mean for the genotypes i at location j; μ is the general mean for genotype i; bi is the regression coefficient for the ith genotype at a given location index, which measures the response of a given genotype to varying locations; Ij is the environmental index, which is defined as the mean deviation from regression for the ith genotype at the jth location; and eij is the mean for experimental error.

Bi= $\sum Y_{ij} I_j / \sum I_j^2$, Where, ∑YijIj is the sum of products and $\sum Ij^2$ is the sum of squares.

Mean square deviations S_{di}^2 is the linear regression, $S_{di}^2 = \sum j_{ij}^2 / (b-2)$, where 'S' is the number of environments and S^2e = the estimate of the pooled error. Further, Everhart and Russell (1966) defined that a variety assortment will be stable if its bi=1.0 and s2di=0. The null hypothesis H0: μ1=μ2=…. = μm was tested by the F-test.

Results and discussion

The AMMI model has been extensively applied in the statistical analysis of multi-environment cultivar trials (Kempton 1984; Crossa *et al.* 1997). The data collected from eleven genotypes grown in three different environments on eleven traits were demonstrated under the combined analysis of variance regarding the appropriate AMMI modeled analysis of variance. The results showed the presence of significant genetic variability for all traits except two parameters, e.g., length of silique and thousand seed weight (Table 1), while both linear and non-linear genotypes and environment interactions were significant for all the parameters except the previous two parameters, number of primary and secondary branches (Table 1).

The mean performances of the different mustard genotypes are presented in Table 2. In the case of first flowering, the genotypes BARI Sarisha-14, SS-75, Maghi, and Improved Tori were desirable for early first flowering as they needed the minimum days to first flower as 27.67, 22.67, 26 and 24.67, respectively, among all the varieties (Table 2). In cases of 50% flowering, BARI Sarisha-14, Sonali Sarisha-75, Maghi (having the minimum days for 50% flowering, 29.44 days) Improved Tori, BINA Sarisha-10, and BINA Sarisha-9exhibited desirability for early 50% flowering (Table 2). The other varieties represented a positive phenotypic index that led them into late 50% flowering, where the maximum time required for 50% flowering was shown in BARI Sarisha-17. In terms of plant height, BARI Sarisha-12, BARI Sarisha-14, SS-75, Maghi, Improved Tori, and BINA Sarisha-9 were desirable for short plant height, and the other five genotypes were tall plant height, while BARI Sarisha-6 was the tallest among all the genotypes (118.39cm) (Table 2).

Table 1. Full joint combined analysis of variance, including the partitioning of G × E interaction of eleven genotypes of B. rapa

Source of variation	df	Mean Sum of squares										
		PH	NPB	NSB	DFF	DHF	DM	NSP	LS	NSS	TSW	TYP
Genotype (G)	10	203.98**	3.93**	6.35**	25.86**	55.25**	52.19**	2439.67**	1.44	69.33**	0.89	15.51**
Environment (E)	2	4.41*	0.15	0.02	11.64**	11.04**	111.55**	910.58**	0.06	18.24**	0.04	0.06
Interaction (G x E)	20	26.85**	0.07	0.14	1.57	0.77	1.68	102.75**	0.00	1.33	0.04	0.03
AMMI Component 1	11	567.69	10.72	17.36**	70.60	150.69	142.34**	6663.78	3.92	189.08	2.47**	42.31
AMMI Component 2	9	61.70	0.00	0.07**	5.10	0.00	0.07*	39.76	0.00	0.00	0.08**	0.00
AMMI Component 3	7	13.37	0.00	0.04**	0.31	0.00	0.02	1.28	0.00	0.00	0.04**	0.00
G x E (Linear)	10	30.43**	0.16	0.19	5.09**	3.18**	24.30**	376.70**	0.01	5.94**	0.05	0.05
Polled deviation	10	24.16**	0.01	0.09	0.38	0.57	1.37	10.91**	0.00	0.36	0.04	0.02
Polled error	60	22.89	0.21	0.24	1.32	1.93	4.59	222.40	0.00	5.45	0.03	0.17

Note: ** and * denote significant at the 1% and 5% levels, respectively.

PH= Plant height (cm), NPB=Number of primary branches, NSB=Number of secondary branches, DFF = Days of first flowering, DHF=Days of 50% flowering, DM= Days of maturity, NSP= Number of siliques per plant, LS=Length of silique (cm), NSS=Number of seed per plant, TSW= Thousand seed weight (g), TYP= Total yield per plant (g)

Table 2. Stability analysis for days to first flowering, 50% flowering, plant height, primary branches of field mustard in three environments (Env.).

Genotype Name	Frist Flowering				50% flowering				Plant height				Primary Branches			
	Mean	Pi	bi	S2di	Mean	Pi	bi	S2di	Mean	Pi	bi	S2di	Mean	Pi	Bi	S2di
BARI Sarisha 6	29.89	1.27	2.07	-0.3	40.44	4.62	1.63	12.78	118.39	16.04	4.44	25.58	7.87	1.85	-5.17	1.27
BARI Sarisha 9	31.11	2.49	-0.47	30.75	39.33	3.51	1.81	19.42	107.32	9.01	6.09	49.59	4.23	-1.78	-5.19	-0.14
BARI Sarisha 12	30.44	1.82	0.05	7.83	39.33	3.51	1.41	3.9	96.56	-5.79	2.90	-1.17	5.84	-0.17	-5.61	1.65
BARI Sarisha 14	27.67	-0.94	2.23	19.76	34.11	-1.70	1.44	-0.47	94.34	-8.00	-0.22	25.29	4.66	-1.35	2.57	-0.15
BARI Sarisha 15	31.22	2.60	3.29	-0.18	39.78	3.95	1.33	2.02	105.17	2.81	1.65	95.68	5.22	-0.79	2.85	3.17
SS 75	22.67	-5.94	2.19	12.74	32.89	-2.92	0.57	12.05	93.14	-9.20	0.42	187.47	6.94	0.92	4.81	0.71
BARI Sarisha 17	30.11	1.49	2.82	25.67	40.78	4.95	1.26	17.2	112.83	10.48	-0.83	89.35	6.61	0.59	1.28	0.05
Maghi	26	-2.61	-0.93	0	29.44	-6.37	1.36	8.59	94.13	-8.22	-2.571	431.7	5.64	-0.37	1.12	0.02
Improved Tori	24.67	-3.95	-0.24	-0.15	30.67	-5.15	0.47	6.44	101.96	-0.39	2.39	159.85	5.37	-0.64	2.98	-0.08
BINA Sarisha 10	30.22	1.61	0.43	5.78	31.44	-4.3737	0.09	15.93	104.63	2.2831	-1.768	113.34	6.33	0.31	5.56	-0.12
BinA Sarisha 9	30.78	2.1616	-0.42	7.13	35.78	-0.0404	-0.37	7.02	97.63	-4.9681	-1.534	-7.02	7.47	1.45	5.81	0.14
E. Mean		28.62				35.82				102.35				6.02		
Environment	E.Index	CV%	LSD (5%)		E. Index	CV%	LSD (5%)		E. Index	CV%	LSD (5%)		E. Index	CV%	LSD (5%)	
Environment-1	1.11	3.46	3.03		1.09	2.4	2.62		-0.67	1.35	4.04		0.13	12.45	2.26	
Environment-2	-0.19	4.21	3.53		-0.21	3.13	3.28		0.11	6.09	18.41		-0.05	3.46	0.61	
Environment-3	-0.91	4.38	3.58		-0.87	5.55	5.71		0.56	5.12	15.55		-0.07	1.45	0.25	

In terms of number of primary branches per plant, BARI Sarisha-9 (exhibited the maximum number 4.23), BARI Sarisha 12, BARI Sarisha-14, BARI Sarisha-15, Maghi, Improved Tori were desirable for a smaller number of primary branches per plant for having negative phenotypic index and the five other genotypes were desirable for large number of primary branches, where the highest number of branches was found in BARI Sarisha-6 (Table 2). In case of number of secondary branches per plant, BARI Sarisha- 6, BARI Sarisha-9, BARI Sarisha 12, BARI Sarisha 14, BARI Sarisha 15, BARI Sarisha 17 represented the lower number of secondary branches per plant. While the other four genotypes showed the opposite, i.e. the highest number of secondary branches per plant (Table 3). In case of days to maturity, BARI Sarisha-14, SS-75, Maghi, Improved Tori, BINA Sarisha- 9, BINA Sarisha-10 showed early maturity, and the rest of the genotypes showed late maturity, for example, BARI Sarisha-17 needed maximum days (Table 3) to mature.

Seven genotypes, BARI Sarisha- 9, BARI Sarisha- 12, BARI Sarisha- 14, BARI Sarisha- 15, BARI Sarisha-17 exhibited a lower number of siliques per plant, whereas the other genotypes, e.g., BINA Sarisha- 9 showed higher number of siliques per plant, (Table 3). In terms of number of seed per silique, all the genotypes produced the high number of seeds per silique (the maximum was in BARI Sarisha- 9) for having positive phenotypic index except BARI Sarisha- 14, Improved Tori, Maghi, and BINA Sarisha-10, which showed the negative phenotypic index (Table 4). In case of 1000 seed weight. BARI Sarisha-9, BARI Sarisha-12, BARI Sarisha-14, BARI Sarisha-15, having negative phenotypic index, had the less weight of 1000 seeds. Among them BARI Sarisha-12 showed the lowest thousand grain weight, while the other six genotypes were suitable for higher thousand grain weight. Among the genotypes, BINA Sarisha-10 had the maximum weight of 1000 seeds (Table 4). In case of yield per plant, BARI Sarisha-6, SS-75, BARI Sarisha-17, BINA Sarisha-10, BINA Sarisha-9 had higher yield per plant, while the other six genotypes showed lower yield per plant.

According to Muradunnabi (2010) genotypes having negative bi value may be grown in poor environments. Environmental conditions might possess various influence on genotype; therefore, certain genotype responses could differ depending on various environment-forming genotype-by-environment (GE) interaction. The phenotypic presentation of different genotypes could be constant in various environments, whereas some others expose significant variation over diverse environments.

The environmental index was calculated for 3 different environments (Tables 2, 3 and 4). Environmental index is considered as the benchmark of deciding whether that respective environment is favorable for specific parameter or not. In the present study, environmental index for environment 1 was positive for first flowering (1.11), 50% flowering (1.10), plant height (-0.67), higher number of primary branches (0.13), number of secondary branches (-0.05), days to maturity (3.41), silique per plant (10.51), silique length (0.03), seed per silique (1.48) weight of 1000 seeds (0.04) and yield/plant (-0.04) (Tables 2-4). The results showed that environment 1 was desirable for late first flowering, late 50% flowering, short plant height, highest number of primary branches, lowest number of secondary branches, late maturity, high number of siliques per plant, long silique, large number of seed per silique, high weight of 1000 seeds and good seed yield performance (Tables 2-4).

For environment 2, the environmental index for early first flowering was -0.19, early 50% flowering (-0.21), plant height (0.11), higher number of primary branches (-0.05), number of secondary branches (0.02), days to maturity (-0.53), silique per plant (-5.13), silique length (-0.08), seed per silique1 (-0.8) weight of 1000 seeds (0.02) and yield/plant (0.08) (Tables 2-4). In contrast to environment 1, the results of environmental index suggested that the environment 2 was desirable for early first flowering, early 50% flowering, long plant height, a smaller number of

Table 3. Stability analysis for secondary branches, days to maturity, silique/plant, silique length of field mustard in three environments (Env.)

Genotype Name	Secondary Branches				Days To Maturity				Siliqua/plant				Siliqua Length			
	Mean	Pi	bi	S2di	Mean	Pi	bi	S2di	Mean	Pi	bi	S2di	Mean	Pi	Bi	S2di
BARI Sarisha 6	2.54	-0.91	1.42	0.68	99.89	2.63	0.83	34.51	165.56	67.36	8.52	3316.21	4.69	0.26	-1.77	0.18
BARI Sarisha 9	1.42	-2.03	1.11	4.37	100.67	3.41	1.26	7.07	66	-32.19	5.44	3777.25	4.19	-0.23	-2.93	0.22
BARI Sarisha 12	3.34	-0.11	0.82	1.82	101.56	4.30	-0.26	-1.41	92.67	-5.53	9.39	585.12	4.44	0.01	-5.32	0.11
BARI Sarisha 14	2.49	-0.96	1.37	0.54	95.89	-1.36	0.71	39.37	68.78	-29.41	0.54	-98.76	3.94	-0.48	-4.46	0.68
BARI Sarisha 15	1.36	-2.10	0.98	8.49	97.89	0.63	1.09	0.68	76.89	-21.30	-5.87	-73.83	5.19	0.76	-0.15	0.16
SS 75	5.56	2.09	1.89	2.7	93.67	-3.58	0.06	14.6	109.22	11.03	-3.21	1334.64	3.44	-0.98	1.49	0.41
BARI Sarisha 17	3.08	-0.38	0.73	0.38	104.89	7.63	1.28	42.93	93.78	-4. 41	-0.78	61.09	4.69	0.26	-0.05	0.44
Maghi	4.91	1.45	1.29	0.84	95.56	-1.69	2.17	116.5	90.33	-7. 86	-1.06	-54.67	4.19	-0.23	-1.22	0.04
Improved Tori	4.08	0.62	-0.02	0.13	96.11	-1.1414	1.15	6.32	87.56	-10.64	1.18	450.62	3.79	-0.63	7.22	-0.03
BINA Sarisha 10	5.36	1.89	0.82	-0.06	92.33	-4.92	1.3	5.93	101.44	3.25	0.76	1616.58	4.19	-0.23	8.08	0.08
BINA Sarisha 9	3.91	0.45	0.58	1.24	91.33	-5.92	1.41	19.47	127.89	29.70	-3.93	1791.34	5.94	1.51	10.11	-0.04
E. Mean		3.46				97.25				98.19				4.42		
Environment	E. Index		CV%	LSD (5%)	E. Index		CV%	LSD (5%)	E. Index		CV%	LSD (5%)	E. Index	CV%	LSD (5%)	
Environment-1	-0.05		13.09	1.32	3.41		0.89	2.65	10. 51		23.14	74.18	0.03	3.46	1.87	
Environment-2	0.02		13.77	1.41	-0. 53		2.6	7.43	-5. 13		5.28	14.49	-0.08	2.87	0.89	
Environment-3	0.03		15.26	1.57	-2. 89		2.73	7.6	-5. 37		3.48	9.53	0.06	3.11	1.36	

Table 4. Stability analysis for seed/siliqua, 1000 seed weight, yield/plant of field mustard in three environments (Env.).

Genotype Name	Seeds/Siliqua				1000 seed weight				Yield/Plant			
	Mean	Pi	bi	S2di	Mean	Pi	bi	S2di	Mean	Pi	bi	S2di
BARI Sarisha 6	26.44	9.69	10.18	124.45	3.46	0.20	0.46	0.45	9.81	3.91	-7.99	10.77
BARI Sarisha 9	12.38	-4.37	8.17	23.47	3.23	-0.03	0.3	0.11	2.69	-3.21	-9.63	8.26
BARI Sarisha 12	13.91	-2.82	8.33	73.78	2.63	-0.63	0.39	0.30	5.84	-0.06	-10.19	5.43
BARI Sarisha 14	14.13	2.62	-0.53	-1.90	2.68	-0.57	1.24	0.17	3.40	-2. 50	3.07	0.04
BARI Sarisha 15	13.83	-2.92	4.84	87.22	2.72	-0.54	0.08	0.30	3.90	-2.00	2.51	14.42
SS 75	22.00	5.24	0.48	32.61	2.59	-0.67	2.07	0.28	7.80	1.90	7.2	5.58
BARI Sarisha 17	17.81	1.05	3.57	18.95	3.98	0.72	2.74	-0.01	7.23	1.33	1.29	1.34
Maghi	13.41	-3.34	1.44	18.42	3.45	0.20	1.11	1.39	4.99	-0.91	1.51	0.31
Improved Tori	13.1	-3.65	-10.05	0.18	3.33	0.08	0.63	0.51	4.21	-1.69	4.83	-0.04
BINA Sarisha 10	14.5	-2.25	-6.24	-1.09	4.15	0.90	0.98	0.43	6.64	0.74	9.49	1.13
BINA Sarisha 9	22.78	6.02	-9.19	-1.9	3.6	0.34	1	0.24	8.40	2.50	8.92	0.91
E. Mean	16.75				3.26				5.90			
Environment	E. Index		CV%	LSD (5%)	E. Index		CV%	LSD (5%)	E. Index		CV%	LSD (5%)
Environment-1	1.48		20.46	11	0.04		2.57	0.25	-0.04		4.6	0.8
Environment-2	-0.80		6.38	3	0.02		7.68	0.74	0.08		8.36	1.47
Environment-3	-0.68		7.32	3.47	-0.06		5.72	0.54	-0.04		7.47	1.29

primary branches, higher number of secondary branches, early maturity, a lower number of siliques per plant, short silique, large number of seed per silique, less weight of 1000 seeds and low seed yield (Tables 2-4).

For environment 3, the environmental index for early first flowering was -0.91, early 50% flowering (-0.87), plant height (0.56), higher number of primary branches (-0.07), number of secondary branches (0.03), days to maturity (-2.89), silique per plant (-5.37), silique length (0.06), seed per silique1 (-0.68) weight of 1000 seeds (-0.06) and yield/plant (-0.04) (Tables 2-4). Unlike environment 1 and 2, the environment 3 were desirable for late first flowering, late 50% flowering, short plant height, a smaller number of primary branches and secondary branches, late maturity, large number of siliques per plant, short silique, large number of seed per silique, high weight of 1000 seeds and medium seed yield (Tables 2-4).

Considering only the IPCA 1, BARI Sarisha- 9 (V2), BARI Sarisha-15 (V5), Maghi (V8), Improved Tori (V9) were low yielding and unstable as they had a low mean for yield and IPCA value between 0 to 2 (Figure 1). In figure 1, the genotype V3 close to the origin indicated that it is insensitive to environmental interaction, that means the genotype is widely adapted. The other genotypes V1, V2, V4, V5, V6, V7, V8, V9, V10, and V11 positioned far from the origin indicated they were sensitive to environmental interactions, meaning they were specifically adapted to the sowing time environment. Again, in figure 1, among the three, Environment 1 is situated most distantly from its origin eliciting strong interactive forces.

Since IPCA 2 scores play a significant role in explaining the GEI, the IPCA 1 scores were plotted against the IPCA2 scores to further explore adaptation (Figure 2). According to figure 3, BARI Sarisha- 6 (V1), BARI Sarisha- 14 (V4), BARI Sarisha- 15 (V5) were outliner indicted unstable genotypes followed by SS-75 (V6), BARI Sarisha- 17 (V7), Maghi (V8). The genotypes, BARI Sarisha- 9 (V2), BARI Sarisha- 12 (V3), BINA Sarisha- 9 (V11) showed more stability when plotting the IPCA1 and IPCA2 scores. The mustard variety BINA Sarisha- 9 (V11) was highly stable as it is placed in the nearest to the center of the axes. (Figure 2).

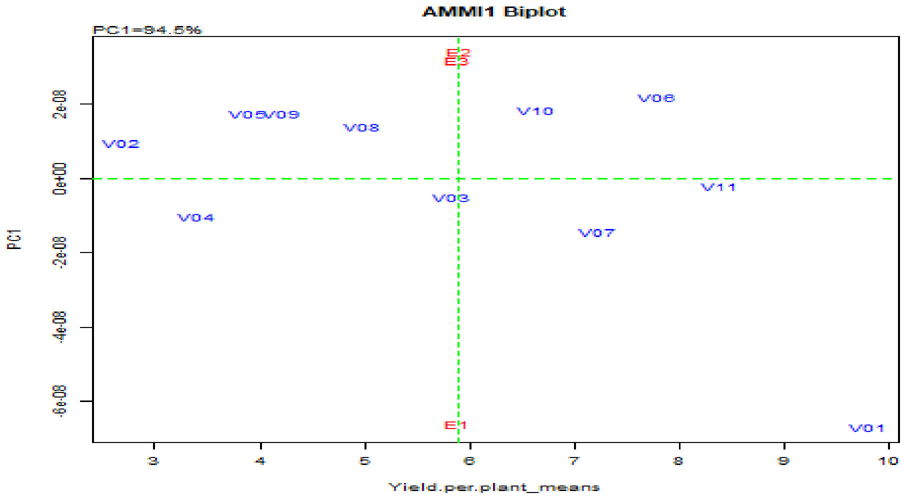

Fig. 1. Interaction biplot of AMMI1 where IPCA1 score (y-axis) plotted against mean yield (x-axis) for eleven genotypes of mustard

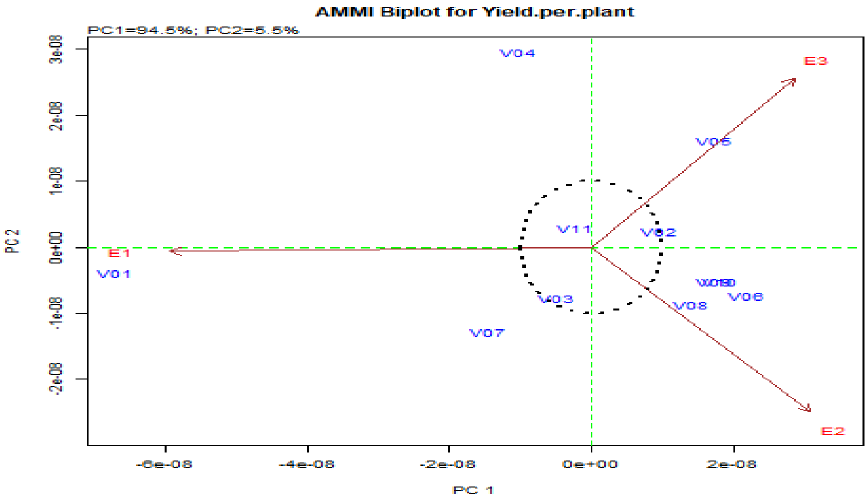

Fig. 2. Interaction biplot of AMMI2 where IPCA2 score (Y-axis) plotted against IPCA1 score (X-axis) for eleven genotypes of mustard

Considering the mean values, bi and S^2di, it can be stated that all the genotypes showed different responses to adaptability under different environmental conditions. According to IPCA1, the genotypes BARI Sarisha- 9, BARI Sarisha- 15 and Improved Tori were highly responsive, hence unstable, and the yield was unsatisfactory. The genotypes BARI Sarisha- 6 BARI Sarisha- 17 and BINA Sarisha- 9 were found to be unstable, but high yielding. The genotypes BARI Sarisha- 12, Sonali Sarisha (SS-75) and BARI Sarisha- 10 were stable, while the latter two genotypes were high yielding and the former genotype was intermediate yielding. IPCA2 scores defines instability for BARI Sharisha 8, BARI Sharisha 1 and BARI Sharisha 15, however, SS-75, BARI Sharisha 17 and Maghi were to a lesser extent. When plotting both scores, BARI Sharisha 9, BARI Sharisha 12 and BINA Sarisha- 9 seemingly portray more stability. Overall, Sonali Sarisha (SS-75) and BINA Sarisha- 10 were found both high yielding and highly stable genotypes.

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References

Balestre NM, Souza JC, Von PRG and Oliveira RL 2009. Yield stability and adaptability of maize hybrids based on GGE biplot analysis characteristics. Crop Breed. Applied Biotechnol. **9**: 226-234.

BARI (Bangladesh Agricultural Research Institute) 2019. A handbook of BARI technology. Bangladesh Agricultural Research Institute, Gazipur, Bangladesh. p. 70.

BBS (Bangladesh Bureau of Statistics) 2021. Bangladesh Bureau of Statistics Division, Govt. of the People's Republic of Bangladesh. p. 123.

Crossa J and Cornelius PL 1997. Sites regression and shifted multiplicative model clustering of cultivar trial sites under heterogeneity of error variances. Crop Sci. **37:** 405-415.

Eberhart SA and Russel WA 1966. Stability parameters for comparing varities. Crop Sci. **6**: 36-40.

Kempton RA 1984. The use of biplot interpreting variety by environment interactions. J. Agric. Sci. Cambridge. **103:**123-25.

Kulsum MU, Hasan MJ, Akter A, Rahman H and Biswas P 2013. Genotype-environment interaction and stability analysis in hybrid rice: an application of additive main effects and multiplicative interaction. Bangladesh J. Bot. **42(1)**: 73-81.

Muradunnahi M 2010. Genotype-environment interaction in hybrid maize (*Zea mays* L.). M.S. Thesis, BSMRAU. Gazipur-1706. p. 21.

Oliveira LN, Duarte ER, Nogueira FA, Silva RB, Faria- Filho DE and Geraseev LC 2010. Efficacy of banana crop residues on the inhibition of larval development in *Haemonchus* spp. from sheep. Ciencia Rural, **40**(2): 458-460

Rahman J, Sultana F, Fatima K, Hasan MM, Gain N, Hossain MS, Chowdhury AK, Rahman A 2022. Genetic diversity of field mustard (*Brassica rapa* L.) and their saturated and unsaturated fatty acids association. SABRAO J. Breed. Genet. 54(2): 249-266

Umeh MO, Edeoga HO and Omosun G 2011. Nitrogen fertilizer type and rate effects on growth and yield response of soybean varieties. Continental J. Agron. **5**(2): 1–8.

Voltas J, Van EF, Igartua EM and Simmonds NW 1981. Genotype (G), environment (E) and GE components of Crop Yields. Exp. Agric. **17**: 355-362.

Wang S, Wang E, Wang F and Tang L 2012. Phenological development and grain yield of canola as affected by sowing date and climate variation in the Yangtze River Basin of China. Crop Pasture Sci. **63(5):** 478-488.

Zobel RW, Wright MW and Gauch HG 1988. Statistical analysis of a yield trial. Agronomy **80**: 388-393.

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